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(74) Common Representative: ALSTOM (SWITZERLAND) LTD; CHSP Intellectual Property, Brown Boveri Str. 7/699/5, CH-5401 Baden (CH).

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(71) Applicant (for all designated States except US): ALSTOM (SWITZERLAND) LTD [CH/CH]; Brown Boveri Strasse 7, CH-5401 Baden (CH).

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(72) Inventors; and

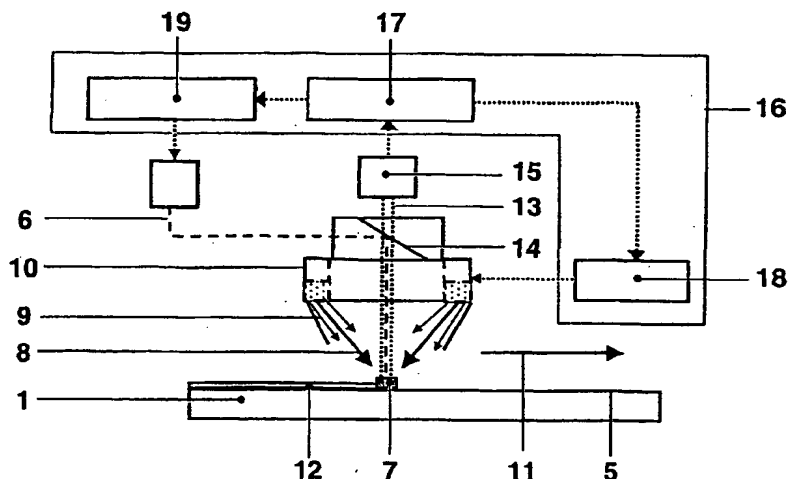
(75) Inventors/Applicants (for US only): FEHRMANN, Bernd [DE/CH]; Stadtbachstrasse 77, CH-Baden 5400 (CH). HÖBEL, Matthias [DE/CH]; Dorfstrasse 82, CH-5210 Windisch (CH).

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(54) Title: METHOD OF CONTROLLED REMELTING OF OR LASER METAL FORMING ON THE SURFACE OF AN ARTICLE



(57) Abstract: It is disclosed a method for controlled remelting of or laser metal forming on the surface (5) of an article (1). A light source and a signal capturing apparatus (15) is moved over the article (1). The light source with a specific power is used to melt the surface (5) of the article (1) locally and to form a melt pool (7). Thereby an optical signal (13) is captured by the signal capturing apparatus from the melt pool (7), and the monitored optical signal (13) is used for the determination of temperature and temperature fluctuations as properties of the melt pool (7). Furthermore, a control system (16) with a feedback circuit is used to adjust at least one process parameter such as the power of the light source such that desired melt pool properties are obtained. Subsequently the melt pool (7) solidifies.

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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FIELD OF THE INVENTION

BACKGROUND OF THE INVENTION

Laser metal forming has been recently used for commercial manufacturing of superalloys due to its attractive potential for repair of locally damaged or worn parts. Indeed, it is possible to selectively add material at desired locations and

to re-establish the full functionality of a component. It is clear that laser repair technology is particularly attractive for the refurbishment of expensive parts that are affected by local damage or local mechanical wear. Turbine blades and vanes are typical examples.

- 5 However, the process is complicated when single-crystal components have to be refurbished. Single crystal blades and vanes can be found in the most heavily loaded rows of modern gas turbines (first or high pressure row). Their mechanical integrity relies on the particular properties due to single-crystal microstructure and the absence of grain boundaries. Reconditioning of such
10 components is only feasible if the single crystal microstructure can be maintained during the repair process.

During laser metal forming substrate material is locally molten and powder (or wire) is injected into the melt pool with a suitable powder (or wire) feeder
15 mechanism. After a certain interaction time (which is determined by the laser spot size and the relative movement between laser and substrate) the molten material resolidifies leading to material build-up on the substrate.

- However, during the solidification of the molten material new grains may form
20 in the melt pool due to constitutional undercooling of the liquid melt. The growth of these newly formed grains leads to undesired build-up of equiaxed material, i.e. material that is oriented in a random manner. As the thermomechanical properties of superalloys greatly depend on the crystallographic orientation and as SX crystal components rely on the benefit of preferable
25 orientation it is obvious that the consequence of equiaxed growth is a serious degradation of the mechanical properties. Moreover, superalloys which do not contain grain boundary stabilizing elements exhibit excessive creep when unwanted grain boundaries are formed. For epitaxial laser metal forming it is therefore crucial to ensure a completely SX microstructure of a part by avoid-
30 ing the so-called columnar to equiaxed transition (CET).

One strategy for ensuring epitaxial growth, i.e. growth with orientation matched to the substrate and without formation of new grains, is to use special process conditions. Laser parameters have to be adjusted in a manner

that a specific ratio between temperature gradient G and the solidification speed V_s is maintained. Both quantities depend not only on laser parameters such as power, power density, advance speed but also on the properties of the substrate and powder (or wire) material.

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Those skilled in the art of laser metal forming are also aware that the onset of (marangoni) convection in the melt pool is one of the main reasons for the undesired CET. Initiation of convection processes in the melt pool leads to fragmentation of the fragile dendrites that form during the solidification of the molten material. By the effect of convective transport dendrite fragments are distributed all over the melt pool where they acts as nucleation sites and promote the formation of equiaxed material. Unfortunately melt pool convection is also affected by other process parameters like mass feed rate, protection gas stream, injection angle. In addition, marangoni convection is not readily detectable without melt pool monitoring.

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So far, several patents have been issued for the laser metal forming process. The basic principle is described in EP-A1-0 558 870, DE-C1-199 49 972, US-A-5,873,960, US-A-5,622,638 or US-A-4,323,756.

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The application of epitaxial material build-up for protective coatings is covered by US-A-6,277,500, applications for generation or refurbishment of single crystal components are described in US-A-6,024,792, EP-A1-0 740 977, WO95/35396 or US-A-5,914,059. Except US-A-6,024,792 none of these patents mentions the significance of the G , V_s parameters in order to obtain the desired single crystal microstructure. US-A-6,024,792 states that the laser power has to be set in a way to obtain adequate values for G and V_s , however, does not suggest a method for automatic laser power control or for avoiding melt pool convections.

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Another patent application, WO95/06540 suggests the use of a pyrometer for interactive laser welding of super alloy articles measuring the substrate pre-heating temperature.

The collection of optical signals from the melt pool is also depicted in US-A-6,122,564. In this patent, an optical monitoring system is connected to a feedback controller in order to adjust the material deposition rate depending on the indicated height of previously deposited material.

In US-A-6,311,099 an apparatus for regulating laser welding parameters is suggested that uses optical signals from the interaction zone. In this patent the optical signal is generated by near infrared radiation originating from the weld pool. The radiation is detected by a CCD camera and processed in order to obtain information about the physical dimensions of the melt pool.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a advanced method for controlled deposition or remelting of material on substrates avoiding hot tearing defects, the columnar to equiaxed transition (CET) and melt pool convection. With material it should be possible to deposit material on single crystal substrates epitaxial with the base material or to transform a previously polycrystalline surface layer into single crystal material.

According to claim 1 a method was found of remelting of the surface of an article and according to claim 2 a second method was found of laser metal forming on the surface of an article.

The method can be used for remelting substrate material in order to re-establish a single crystal microstructure in the surface zones of the substrate, to transform a previously polycrystalline surface layer into single crystal material, to coat single crystal articles with a single crystal coating or for the repair of single crystal turbine components. Due to matched thermo-physical properties of solidified and base material the method leads to reduced stress and therefore to greater lifetime of the components.

With the online monitoring system and using automatic feed-back control of at least one process parameter such as laser power it is possible to establish and maintain optimum process conditions. In this favorable case the columnar to equiaxed transition (CET) and melt pool convection are avoided and a temperature field is created in the melt pool which leads to defect-free, epitaxial growth of the deposited material. Thus, it is possible to add new material without creation of grain boundaries. Beside the laser power process parameters like the relative speed between laser beam and the substrate, the carrier gas flow and mass feed rate of added material can be controlled.

Preferably as light source a fibre coupled high power diode laser is used. The inventive method combines laser power delivery, material supply and process monitoring in a dedicated laser/powder head. With this device the powder injection can be concentric with respect to the cone of captured optical signals from the melt pool or the cone of captured optical signals from the melt pool concentric with respect to the light source focussing cone. With the help of a dichroitic mirror infrared (IR) radiation from the melt pool is collected through the same optics which is used for laser focussing. The dichroitic mirror transmits laser light and reflects process light or vice versa.

The process signal from the melt pool can be coupled to a pyrometer or another fiber-coupled detector. For this purpose the optical properties of the monitoring system are chosen such that the measurement spot is smaller than the melt pool and located at the center of the melt pool. In a preferred embodiment according to the invention the optical signal is captured from the center and vicinity of the laser focal spot using a single optical fiber, an imaging fiber bundle or a charged coupled device (CCD) camera that is equipped with suitable optical filters. This information is used to determine the temperature a single spot or simultaneously at several locations in the center and in the vicinity of the melt pool. In a second case temperature gradients in the laser interaction zone can be analyzed.

The online feed back control of the laser power is decoupled from the main process control by means of a separate microprocessor. This allows faster parallel processing in real-time, i.e. independent from the operating system.

5 In another embodiment post-processing of the optical signal from the melt pool is used for quality control: The analysis of the measured data allows to optimize process parameters such that a desired microstructure is obtained. Recording of monitoring signals serves also for documentation purposes and for ensuring consistent product quality.

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Moreover, dedicated commercially available software tools with enhanced functionality can be used for the realisation of the control system. As a consequence short loop times and advanced PID control features such as gain scheduling can be realised.

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BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are illustrated in the accompanying drawings, in which

- 20 Fig. 1 illustrates a gas turbine blade,
Fig. 2 illustrates an apparatus for carrying out the invention the present invention,
Fig. 3 illustrates an overall control system for carrying out the invention,
25 Fig. 4 illustrates an example of the invention and
Fig. 5 illustrates a second example of the invention.

The drawings show only the parts important for the invention. Same elements will be numbered in the same way in different drawings.

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DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a single crystal (SX) or directionally solidified (DS) article 1 such as blades or vanes of gas turbine engines, the gas turbine blade com-

prising a root portion 2, a platform 3 and a blade 4 and having a surface 5. The article 1 can as an example be made from a nickel or cobalt based super alloy. Investment casting methods for producing such SX or DS articles are known e.g. from the prior art US-A-4,96,501, US-A-3,690,367 or EP-A1-0 749 790. These articles 1 are normally made from a nickel or cobalt base super alloy.

The herein disclosed method can be used for remelting substrate material of the article 1 in order to re-establish a single crystal (SX) microstructure in the surface zones of the substrate or to transform a previously polycrystalline surface layer into SX material. In addition this method can be used for SX-coating application on SX-articles 1 or for the repair of single crystal (SX) turbine components. The underlying single crystal bulk material will act as a crystal seed for the remolten material. Due to matched thermo-physical properties the method leads to reduced stress and therefore to greater lifetime of the components.

It can be seen from the previous paragraph that high thermal gradients with the melt pool 7 are crucial for single crystal solidification. For this reason high power lasers such as CO₂, (fibre coupled) Nd-YAG or (fibre coupled) high power diode lasers offer a particularly attractive choice as a light source. Laser radiation can be focussed to small spots and generate thermal gradients in excess of 10⁶ K/m. It is beneficial if the laser intensity is uniform over the heated area, which can be achieved by fiberoptic beam delivery. As laser power is very easily controlled, it is ensured that the criterion for single crystal solidification is maintained during the whole operation.

If during this operation the ratio G^n/V_s (where G is the temperature gradient in the melt pool, n is a material constant and V_s is the solidification speed) is kept above a material dependent threshold value, the subsequent solidification will occur epitaxially, i.e. without creating new grain boundaries.

In a typical application the laser will be focussed to a spot size of 1-3 mm diameter. Preferably the laser would be either of the Nd-YAG or high power

diode laser type. These lasers operate in the near infrared and about 30-40 % of the incident radiation is absorbed by typical super alloys. The laser beam will move at relatively slow speeds (approx. 1-10 mm/s) over the affected zones and operate in the conduction welding mode. Laser intensities of $1 \cdot 10^3$ W/cm² to $5 \cdot 10^4$ W/cm² will remelt a zone reaching up to 500µm below the surface. Larger penetration depths can be achieved by further reducing the processing speed or by preheating the article 1 prior to the melting of the surface 5 to a desired temperature in the range of 500 – 1000°C, e.g. with a high frequency generator. On preheated articles, however, thermal gradients are smaller and it is more difficult to meet the G^n/V_s criterion. On the other hand the risk of hot tearing defects during the whole operation is reduced.

Fig. 2 shows as an example an apparatus for controlled laser metal forming on the surface 5 of the article 1 according to the present invention. A laser beam 6 is moved over the surface 5 of the article 1 (or the article 1 is moved relative to the laser beam) thereby locally melting the surface 5 to form a melt pool 7. For coating or other laser metal forming applications material in the form of jet of powder 8 with a carrier gas 9 by means of a feeder 10 or a wire is added to the melt pool 7. From the melt pool 7 an optical signal 13 is continuously captured and used for the determination of the temperature, the temperature fluctuations and existing temperature gradients as properties of the melt pool 7. In one embodiment as seen in Fig. 2 the powder 8 injection can be concentric with respect to the cone of captured optical signals 13 from the melt pool 7.

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As seen from the Fig. 3, the information of the optical signal 13 is used in a feedback circuit within a control system 16 to adjust process parameter such as the laser power by means of a controller 19, the relative speed between the laser beam 6 and the substrate, the flow rate of the carrier gas 9 and the mass feed rate of the injected powder 8 by means of a controller 18 in a way that desired melt pool 7 properties are obtained. For the method of remelting of the surface 5 of the article one or a combination of the process parameters laser power and/or the relative speed between the laser beam 6 and the arti-

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cle 1 is used. Subsequently the melt pool 7 solidifies as indicated in Fig. 2 with reference number 12.

The method uses a combination of a concentric feeder 10, a fiber coupled
5 laser and an on-line monitoring system with real time capability. With the help of the online monitoring system optimum process conditions are established and maintained where the columnar to equiaxed transition (CET) and melt pool convection are avoided. Hence, defect-free, epitaxial growth of the deposited material is observed. It is thus possible to add new material without
10 creation of grain boundaries.

The new method combines laser power delivery, material supply and process monitoring in a dedicated laser/powder head as shown in Fig. 2. With the help of a dichroitic mirror 14 infrared (IR) radiation from the melt pool 7 is collected
15 through the same optics which is used for laser focussing. The dichroitic mirror 14 transmits laser light and reflects process light of the optical signal 13 or vice versa.

The optical signal 13 from the melt pool 7 is coupled to a pyrometer 15 or
20 another fiber-coupled detector which allows the online determination of the melt pool temperature. For this purpose the optical properties of the monitoring system are chosen such that the measurement spot is smaller than the melt pool and located at the center of the melt pool 7. In another embodiment according to the invention the optical signal 13 is captured from the center and
25 vicinity of the laser focal spot using an imaging fibre bundle or a charged coupled device (CCD) camera that is equipped with suitable optical filters. This information is used to determine the temperature a single spot or simultaneously at several locations in the center and in the vicinity of the melt pool. In a second case temperature gradients in the laser interaction zone can be
30 analysed.

The cone of captured optical signals 13 from the melt pool 7 can be concentric with respect to the laser focussing cone. The symmetry of this arrangement ensures that laser-powder interaction does not change during movements on

complex shaped components. This leads to consistent high quality of the process.

Fig. 3 shows the overall control system 16 for carrying out the invention. Besides a main process control 16 a controller 18 for controlling the feeder 10 and the whole apparatus and a controller 19 for controlling the laser is provided. The temperature information is used for the adjustment of process parameters such as the laser power, the relative speed between the laser beam 6 and the article 1, the feed rate of the injected powder 8 with the carrier gas 9 or an injected wire. For the method of remelting of the surface 5 of the article only one or a combination of the process parameters laser power and/or the relative speed between the laser beam 6 and the article 1 is used. This automatic feed-back control of the laser power by means of the controller 19 allows to establish a temperature field which is favourable for epitaxial growth. Moreover, the monitored optical signal 13 from the melt pool 7 allows to detect the onset of marangoni convection. Avoiding marangoni convection in the melt pool 7 will reduce the risk of hot tearing defects during solidification of the molten material.

As seen in Fig. 3, the online feed back controller 19 of the laser power is decoupled from the main process control 17 by means of a separate microprocessor. This allows faster parallel processing in real-time, i.e. independent from the operating system.

In another embodiment postprocessing of the optical signal 13 from the melt pool 7 is used for quality control: The analysis of the measured data allows to optimize process parameters such that a desired microstructure is obtained. Recording of monitoring signals serves also for documentation purposes and for ensuring consistent product quality.

Moreover, dedicated commercially available software tools (e.g. LabView RT) with enhanced functionality can be used for the realisation of the control system 16. As a consequence loop times <10 ms and advanced PID control

features such as gain scheduling, which means the use of different sets of PID parameters in predefined temperature intervals can be realised.

Example of the invention

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As an example of the invention as shown in Fig. 4 a 300 µm polycrystalline surface layer (of plasma sprayed coating material) was remelted and transformed into an epitaxially solidified surface layer. The matched orientation of the (fine) dendrites in the remolten area can be seen. Laser parameters were:

10 P=220 W, v=1 mm/s, spot diameter: 2.5 mm.

A second example of the invention is shown in Fig. 5, where a 550 µm SX protection layer is deposited on a part made of SX turbine material. A subsequent re-melting step re-melts the surface layer of the deposit and leads to a very smooth surface finish and improved quality of the microstructure. In this case process parameters were: P=270 W, v=2 mm/s, powder feed rate: 2.4 g/min, laser spot diameter 1.8 mm for the deposition step and P=240 W, v=4 mm/s, laser spot diameter: 2.5 mm for the subsequent re-melting step.

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REFERENCE NUMBERS

- | | |
|-------|--|
| 1 | Article, e.g. blades or vanes for gas turbines |
| 2 | Root portion |
| 3 | Platform |
| 25 4 | Blade |
| 5 | Surface of article 1 |
| 6 | Laser beam |
| 7 | Melt pool |
| 8 | Powder |
| 30 9 | Carrier gas |
| 10 | Feeder |
| 11 | Direction of movement |
| 12 | Solidified material |
| 13 | Optical signal |
| 35 14 | Dichroitic mirror |
| 15 | Pyrometer |
| 16 | Control system |
| 17 | Main process control |
| 18 | Controller for feeder 9 |
| 40 19 | Controller for laser |

CLAIMS

1. A method for controlled remelting of the surface (5) of an article (1), the method comprising the steps of

5 (a) moving a light source and a signal capturing apparatus and the article (1) relative to each other, thereby

(b) melting locally the surface (5) of the article (1) using the light source with a specific power for forming a melt pool (7),

10 (c) capturing an optical signal (13) from the melt pool (7) using the signal capturing apparatus,

(d) using the monitored optical signal (13) for the determination of temperature and temperature fluctuations as properties of the melt pool (7),

(e) using the information of the temperature and temperature fluctuations of the melt pool (7) from the optical signal (13) within a control system

15 (16) in a feedback circuit to adjust as process parameters the laser power and/or the relative speed of the light source to article (1) such that desired melt pool properties are obtained and subsequently

(f) solidifying the melt pool (7).

20 2. A method for controlled laser metal forming on the surface (5) of an article (1), the method comprising the steps of

(a) moving a light source and a signal capturing apparatus and the article (1) relative to each other, thereby

25 (b) melting locally the surface (5) of the article (1) using the light source with a specific power for forming a melt pool (7),

(c) injecting powder (8) with a carrier gas (9) or a wire into the melt pool (7).

(d) capturing an optical signal (13) from the melt pool (7) using the signal capturing apparatus,

30 (e) using the monitored optical signal (13) for the determination of temperature and temperature fluctuations as properties of the melt pool (7),

(f) using the information of the temperature and temperature fluctuations of the melt pool (7) from the optical signal (13) within a control system (16) in a feedback circuit to adjust as process parameters one or a

combination of the power of the light source, the relative speed between the light source and the article (1), the mass feed rate of the added material and/or of the carrier gas (9) such that desired melt pool properties are obtained and subsequently

5 (g) solidifying the melt pool (7).

3. The method of claim 1 or 2, comprising the step of adjusting the process parameters such that melt pool properties are obtained to avoid columnar to equiaxed transition (CET) during solidification of the melt pool (7).

10 4. The method of claim 1 or 2, comprising the step of adjusting the process parameters such that melt pool properties are obtained to avoid convection in the melt pool (7).

15 5. The method of claim 2, wherein the article (1) consists of single-crystal (SX) or directionally solidified (DS) microstructure comprising the step of adjusting the melt pool properties to obtain epitaxial material build-up with thermo-physical properties of the deposit matched to those of the article (1).

20 6. The method of claim 1 or 2, wherein the surface (5) of the article (1) is remelted in order to re-establish a single crystal (SX) microstructure or to transform a polycrystalline surface layer into a single crystal (SX) structure.

25 7. The method of claim 1 or 2, wherein the light source is moved in respect to the article (1) or the article (1) is moved in respect to the light source.

8. The method of claim 1 or 2, wherein the light source power control is handled by a controller (19) with a different processor than that used for main process control (17) within the control system (16).

30 9. The method of claim 8, comprising the step of operating the light source power controller (19) in real time.

10. The method of claim 1 or 2, wherein gain scheduling is used for predefining PID control parameters within the control system (16).

11. The method of claim 1 or 2, wherein post-processing of the optical signal (13) from the molten (7) pool is used for quality control purposes, optimization of process parameters and/or process documentation.

12. The method of claim 1 or 2, wherein the captured optical signal (13) from the melt pool (7) is directed to a pyrometer (15).

13. The method of claim 12, comprising the step of capturing the optical signal (12) from a region in the center of the melt pool (7), whereby the pyrometer (15) measurement spot is smaller than the light source spot.

14. The method of claim 1 or 2, comprising the step of capturing the optical signal (13) by a fiber-coupled detector.

15. The method of claim 1 or 2, comprising further the steps of

- (b) capturing an optical signal (13) from the centre and vicinity of the light source focal spot,
- (c) using an optical fiber or an imaging fibre bundle or a CCD camera to capture the optical signal (13),
- (d) using the optical signal (13) to determine the temperature at several locations in the center and in the vicinity of the melt pool (7) and
- (e) using the information to determine temperature gradients in the light source interaction zone.

16. The method of claim 2, wherein the powder (8) injection is concentric with respect to the cone of captured optical signals (13) from the melt pool (7).

17. The method of claim 1 or 2, wherein the cone of captured optical signals (13) from the melt pool (7) is concentric with respect to the light source focussing cone.

18. The method of claim 1 or 2, comprising the step of using a dichroitic mirror (14) that transmits light from the light source and reflects light of the optical signal (13) or vice versa.

5 19. The method of claim 1 or 2, comprising the step of using a fibre coupled high power diode laser as light source.

20. The method according to any of the claims 1 to 20, wherein the article (1) is a gas turbine component made from a nickel or cobalt base super alloy.

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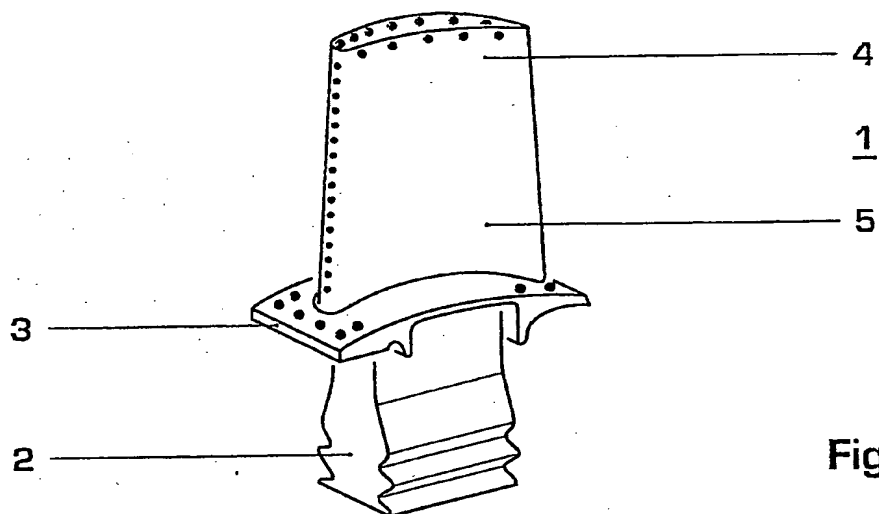


Fig. 1

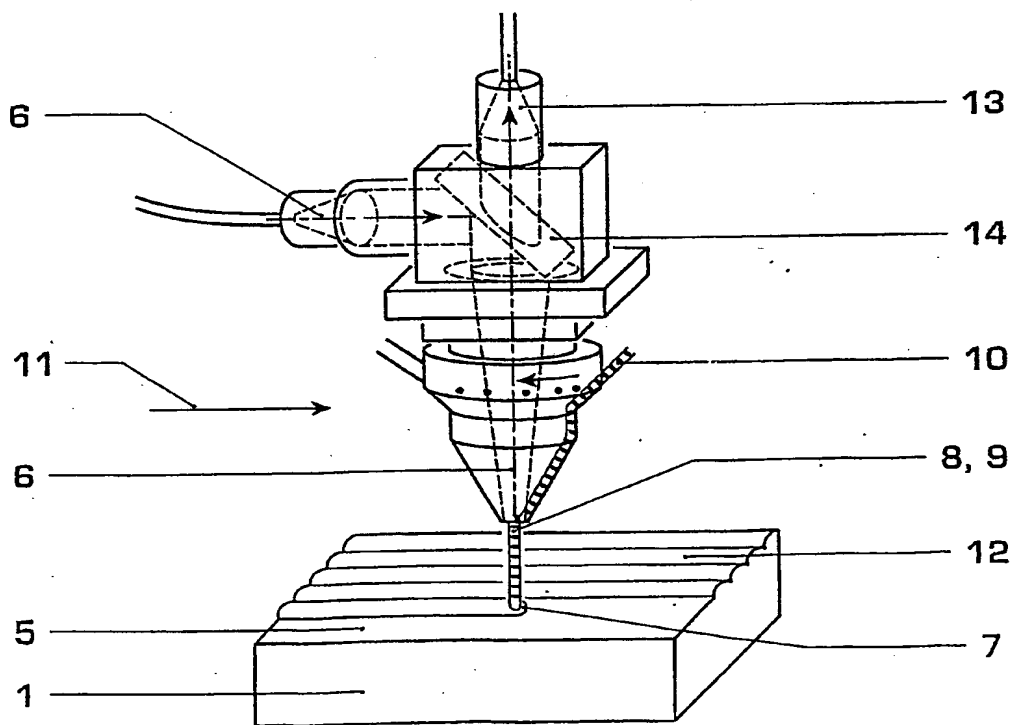


Fig. 2

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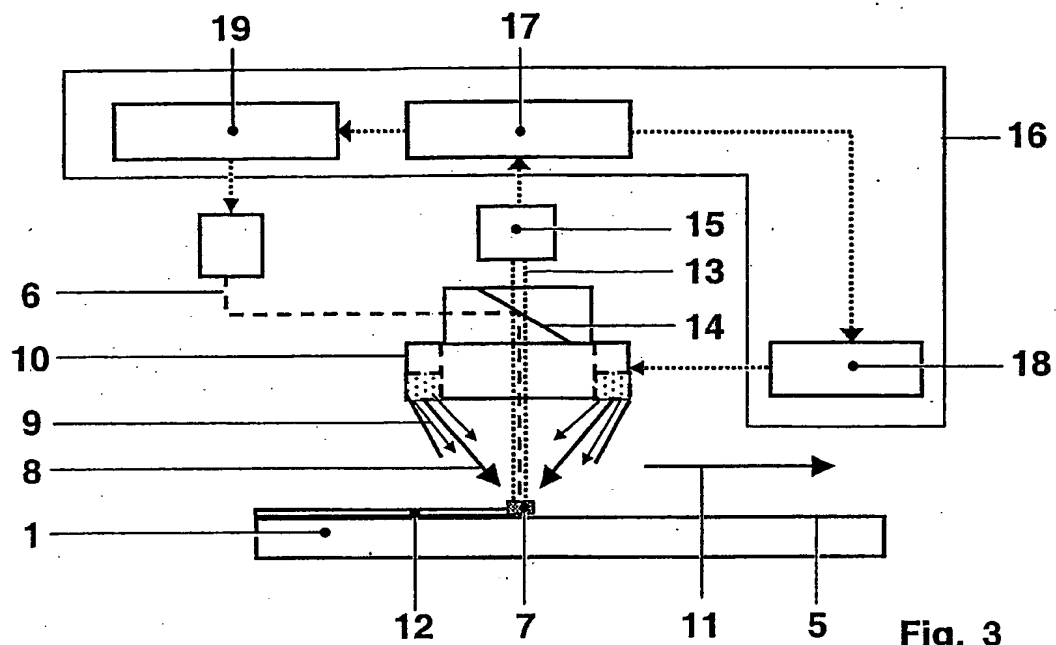


Fig. 3

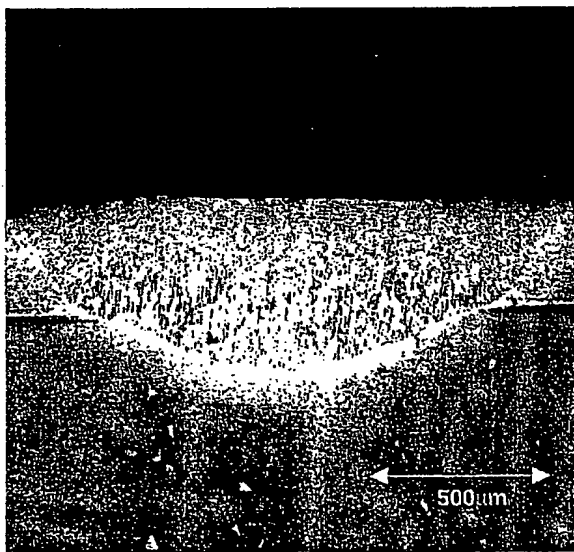


Fig. 4

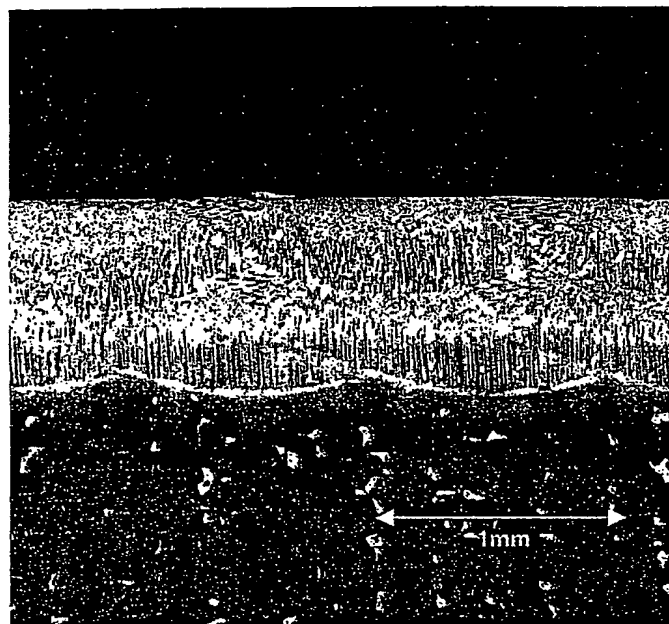


Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No

PCT/CH 03/00098

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B23K26/03 B23K26/34 F01D5/00 F01D5/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B23K F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal; WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 046 426 A (F.P. JEANTETTE ET AL) 4 April 2000 (2000-04-04) column 1, line 9 -column 2, line 8 column 5, line 1-21 column 8, line 8-27 column 10, line 1-49; figure 9	2,4,7,9, 11,12,16
X	DE 198 53 733 C (FRAUNHOFER GES FORSCHUNG) 24 February 2000 (2000-02-24)	1,7,9, 12,13,18
Y	the whole document	2-6,20
Y	US 6 024 792 A (KURZ WILFRIED ET AL) 15 February 2000 (2000-02-15) cited in the application the whole document	2-6,20

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☒ Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search

10 April 2003

Date of mailing of the international search report

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	EP 1 001 055 A (ABB RESEARCH LTD) 17 May 2000 (2000-05-17) the whole document	2-6,20
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Information on patent family members

International Application No

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